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SOUR GAS FACILITIES: A CASE STUDY OF PUBLIC RISK IN ALBERTA

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1.1 HISTORICAL ACCOUNT

On October 2, 1973, the escape of hydrogen sulphide gas from an oil well blowout in central Alberta prompted the evacuation of 800 persons from towns, villages and farms within an area of at least 200 km^2. Reports of "huge clouds of poisonous gas rolling across the countryside" were carried on local, national and international newscasts. The Deputy Premier, two cabinet ministers and other high ranking government officials rushed to the scene. Within a day, the oil company and its contractors had brought the well under control and residents were allowed to return home. The investigation (New Norway Sci. Comm. 1974) and public inquiry which followed revealed that there was no injury to humans or animals and furthermore, that the potential for injury existed only in close proximity to the well. Media coverage had greatly exaggerated the hazard, the large-scale evacuation being an overreaction to the perceived threat. Although there had been incidents of uncontroled sour gas releases (sour gas is natural gas containing hydrogen sulphide) prior to this, public safety had not been a major issue since most had occurred in sparsely populated regions.

In 1974, the petroleum industry expressed concern about the potential problem caused by the "encroachment of population centres on sour gas operations". The Alberta Petroleum Industry Government Environmental Committee (APIGEC) consisting of representatives of the petroleum industry, Alberta Environment, Alberta Energy and Natural Resources, and the Energy Resources Conservation Board, examined the geographical extent of sour gas facilities, the history of previous releases, the toxicology of hydrogen sulphide, the dispersion of gas once released and the regulatory situation (Alberta Dept. of the Environment. It concluded that:

1. there are over 100 sour oil and gas fields in the province, of which 25 are located within 16 km of a city, town or village;
2. Sour gas pipeline breaks averaged about seven per year, most being small and due to corrosion;
3. well blowouts averaged one per year out of 370 wells in the province.

It recommended that appropriate regulations be enacted to prohibit new subdivision development within a 100 parts per million (ppm) hydrogen sulphide isopleth of any sour gas operation. The location of the isopleth (line connecting points of equal concentration) was to be calculated using "worst case" assumptions for the source and atmospheric conditions.

Because the authority to approve subdivision is vested in a number of regional and city planning commissions (operating under the auspices of the Alberta Planning Board), the staffs of these planning commissions were all made aware of this recommendation. In June 1975, the Edmonton Regional Planning Commission formally adopted a set of subdivison guidelines (Edmonton Regional Planning Comm. 1975) embodying the 100 ppm isopleth restriction and setting out an administrative mechanism. One significant feature of the guidelines was that the onus of providing information about sour gas operations and the calculated 100 ppm isopleth was placed upon the applicant for subdivision. The Edmonton Regional Planning Commission also urged the Alberta Planning Board to consider their guidelines for province-wide implementation.

In practice, however, information about sour gas operations actually came from the Energy Resources Conservation Board (ERCB), the central authority for the entire oil and gas industry. By virtue of the referral system used by planning commissions, the ERCB was also called upon to review subdivision proposals near sour gas facilities. Thus the burden of providing information and calculating isopleths fell largely upon the ERCB.

In July 1975, a meeting was convened with representatives of the ERCB, Alberta Environment, the Alberta Planning Board, and the various planning commissions to discuss the sour gas policy and the best means of administration. It was generally agreed that province-wide regulations were necessary and that the 100 ppm isopleth would define the critical area. It was noted that the danger is of finite duration, lasting only as long as a given well produces gas, and that in perhaps 30 years the danger would have passed and the lands would again become eligible for subdivision and development. But there was still the problem of existing settlements within the critical areas of existing sour gas operations. The concept of a risk-benefit tradeoff was broached by Alberta Environment with the distribution of the paper by Starr (1975).

The City of Calgary was wrestling with the problem of two large sour gas wells located 1.6 km northeast of the city. The 100 ppm isopleth from these wells extended well into the city and if the recommendation was to be followed, 7.7 km^2 of city land would go undeveloped at a time when great pressure was being put on the residential market. Consultants had determined that the probability of an accidental release of H_2S was 1 in 8000 for each well, which was considered to be "fairly high" and to support the 100 ppm restriction (D & S Petroleum Consultants 1975). This was the first attempt to apply probability concepts to the problem. Alternative solutions were identified as:

1. relocate the well heads (cost $150,000.00 per well);
2. close the well (lost revenue $4,000,000.00);
3. wait 25 years for the gas pool to be depleted.

The City of Calgary representative expressed a desire for a refinement of the probabilities before the formation of any policy. It was also suggested that low density development within the 100 ppm isopleth be considered. An ad hoc committee consisting of representatives of the ERCB, Alberta Environment and the Alberta Planning Board was struck to draw up some tentative guidelines. Steps were also taken to reduce the volume of referrals to the ERCB by providing information packages to each planning commission.

The planning commissions, however, experienced difficulty in applying the information to specific situations and in keeping the information up to date. They were further hampered by the tentative nature of the provincial policy and confusion over the way to calculate the isopleths. The ERCB encountered similar problems in administering its own informal guidelines restricting the construction of new sour gas facilities in populated areas.

During the latter part of 1975 and the early part of 1976, the ERCB and Alberta Environment expended considerable effort in gathering information about sour gas experience elsewhere in North America and in Europe. An extensive bibliography on sour gas dispersion was compiled, and relevant regulations from other jurisdictions assembled. For example, it was found that the Texas Railroad Commission also used a "100 ppm radius of exposure" to delineate a control area.

Pursuing the idea of quantitative risk assessment, Alberta Environment contacted the Atomic Energy Control Board (AECB) of Canada to obtain the benefit of the nuclear industry's extensive experience in this area. (This exchange was facilitated by the AECB's interest in hydrogen sulphide problems and the fact that they had paid a visit to Alberta after the oil well blowout to learn about the emergency response measures that had been taken.) The AECB responded with an annotated bibliography, copies of numerous important papers and an extensive reference list. With this base information, Alberta Environment engaged the services of Dr. Whittaker of the University of Alberta to document the rationale for using risk analysis and develop the framework for quantifying the risk from sour gas facilities (Whittaker 1976).

After several revisions, the tentative subdivision guidelines proposed in the summer of 1976 contained one major change: subdivision to a density of eight lots per quarter section or parcels of not less than 8 ha (20 acres) in size were to be permitted within the 100 ppm isopleth. An important feature of all subdivision guidelines is that they are always subject to waiver by, and appeal to, the Alberta Planning Board. These proposed guidelines were then submitted to the Canadian

Petroleum Association and the Independent Petroleum Association of Canada for comment by the sour gas operators.

Meanwhile, there had been two more well blowouts resulting in evacuation of nearby farms and settlements, and application of the 100 ppm guideline was beginning to have serious ramifications. Firstly, land values were being affected by the restriction on subdivision. The strenuous objections of landowners in west central Alberta to the drilling of a sour gas well near their property prompted the first ever public hearing on a gas well. As a result the drilling site was relocated.

Secondly, the growth of several communities was threatened, for example, the entire village of Crossfield was found to lie within the exclusion zone. Hence, concern was expressed over the reliability of the methods used to calculate the isopleth distance. The ERCB upon advice from Alberta Environment had developed some simple plume models for gas wells which were also applied to pipelines under the assumption that it would take twenty minutes to exhaust a pipeline. The ERCB hired a consultant (Intera Environ. Consultants 1976) to refine the isopleth calculation using a numerical simulation model. Alberta Environment hired Dr. Whittaker to extend his earlier work and do a detailed risk assessment (Whittaker 1977). Failure modes were identified and their probability of occurrence determined from historical records. In combination with wind and stability data, the probability of experiencing hazardous-to-life concentrations (>500 ppm) within the town boundaries was calculated using Monte Carlo Simulation to sum over all possible cases. The risk was found to be in the order of 1/3000, clearly unacceptable by usual society norms. The only mitigative measure that made a significant reduction in the risk was the removal of the pipeline. This was a general conclusion even though the different dispersion models gave considerably different results.

The subsequent ERCB staff report recommended a number of special safety measures, abandonment of one pipeline and suspension of one well. The ERCB then ordered the operator to relocate the offending pipeline, an order which eventually led to a public hearing over the new route. The hearing provided a forum for interested members of the public to debate the idea of decision-making based upon probability calculations. The operators objected to the number used for the failure rate on the grounds that they had a better than average operating history, but did accept that risk could be so calculated. A group of property owners affected by the relocated pipeline argued that the only way risk could be assessed was from the number of fatalities directly attributable to pipeline ruptures. The village was convinced that the existing line presented an unacceptable risk. The ERCB Decison Report also found fault with the data base, but was generally in agreement with the methodology (ERCB 1978b). Thus it was publicly accepted that it is possible to determine the risk inherent in a system, that there are levels of risk which society will accept, and that such levels can be subjected to public debate.

The town of Okotoks was likewise constrained by the existing subdivision policy. Under contract to the ERCB, Whittaker (1978) extended his earlier work to incorporate the probability of receiving a lethal dose during the passage of a gas cloud of a given average concentration. This accounted for concentration fluctuations within the plume and exposure time. The control zone was then to be defined by the calculated acceptable risk contour, with the level 10^{-6} being proposed.

Although specific problem areas were being subjected to increasingly sophisticated risk assessment, the provincial policy continued to hinge on the 100 ppm isopleth criterion using worst case conditions: the largest possible gas flow in the most unfavourable weather conditions. Whittaker's first report had proposed that worst case evaluation be dropped and that all possible cases be considered along with their probability of occurrence. The ad hoc committee responsible for the guidelines had considered this approach but had decided that it was too complicated for ready implementation. They had also decided to prohibit subdivision entirely within the 500 ppm isopleth, the "dangerous to life" zone, and to implement these guidelines for a trial period of two years. This was accomplished by placing them in The Subdivision Regulation (Alberta Planning Board responsible) and in an Interim Directive (ERCB responsible).

This decision focussed attention on the manner of calculating the worst case isopleths. The numerical model used by one consultant gave quite different results

from the simple model originally used by the ERCB and Alberta Environment. It became apparent that the twenty-minute rule was not valid and that, in fact, a ruptured pipeline would empty in a matter of a few minutes. Alberta Environment then proposed a simple puff model, effectively assuming an instantaneous release of gas. This, however, gave much larger isopleth distances, a result not at all appreciated by land developers or sour gas operators. The ERCB engaged a different consultant (Dilworth et al. 1977) with a multiple puff dispersion model and a refined pipe gas flow model, but the results were little different. Alberta Environment commenced development of an integrated puff atmospheric dispersion model (Choukalos 1978). A variant of this model was turned over to the ERCB and became the basis for their own multiple puff model (ERCB 1978a).

The refined puff models gave results not greatly different from the simple puff models, but there were large differences between the puff model predictions and the numerical model predictions. Isopleth distances for the former were generally two or three times larger than for the latter. This produced considerable confusion in determining how much land was affected. At one point the ERCB was holding applications for 130 km of pipeline because it would potentially restrict subdivision on some 500 sections of land, prohibit it on another 175 sections and block the expansion of two towns. Technical discussions were unable to resolve the computational differences, but it was recognized that a number of assumptions about source conditions might be responsible. The ERCB and Alberta Environment proposed a field experiment to APIGEC for verification purposes. As a first step APIGEC commissioned a literature review of all relevant aspects (Bander 1979).

The confusion about calculation methods caused considerable delay in processing both pipeline and subdivision applications. In fact, virtually all applications for sour gas facilities were being scheduled for hearings, a rather protracted process that heretofore had been used only for major projects. Contributing to the problems with the calculation methods was an award by the Surface Rights Board to a landowner for the injury to values of land contained within the isopleths. Shortly thereafter a group of 11 sour gas producers led by Shell Canada Resources Limited proposed to APIGEC an immediate field verification of the isopleth prediction techniques to be carried out in four phases:

1. sensitivity analysis of dispersion models to identify the most significant variables;
2. preliminary field tests to evaluate experimental techniques and gather preliminary information on source behaviour;
3. comprehensive field experiments to obtain complete, reliable data on the release and dispersion of gases from a pipeline rupture;
4. model testing and verification to select the best model and and optimize its performance.

The APIGEC quickly approved the first two phases.

The sensitivity study (APIGEC 1978) revealed that plume rise and pipeline blowdown rate were the most critical variables in calculating isopleth locations. The preliminary pipe burst tests (APIGEC 1979) indicated that in a typical rupture there is virtually no plume rise, confirming the early worst case assumption. Confirmation of the consultant's pipeline blowdown model was also obtained. This meant that the pessimistic assumptions used in the isopleth calculations were reasonable and that the unacceptable large exclusion areas would not be reduced by virtue of large plume rise or different blowdown rates. In order to alleviate the massive land use conflict, worst case assessment would have to be abandoned in favour of risk analysis.

Not yet comfortable with Risk Analysis, the ERCB hired a United States consultant (Battelle 1978) to review the risk studies completed up to that point and recommend improvements. The ERCB (Atwell et al. 1979) then proceeded to do a risk assessment based on "statistical" or "aggregate" risk to a population. Hydrogen sulphide concentrations were predicted using the multiple puff atmospheric dispersion model and for different concentration ranges a different fractional fatality was assigned (Fig. 1.1); for example, if the H_2S concentration was between 500 and

1000 ppm, 50% of the population was considered to have received a fatal dose. The concentration fields were than superimposed on a populated area of 1 km^2 at various distances from the pipeline and with various population densities. From the total number of fatalities it was then possible to construct two graphs:

1. the "average individual risk" versus distance from the pipeline (Fig. 1);
2. the number of events per year versus the number of fatalities (so-called "risk spectrum").

The former curve underwent a sharp initial decline and then levelled off. This suggested that the location of the "break-point" or "point of diminishing returns" might provide a suitable demarcation of the buffer zone.

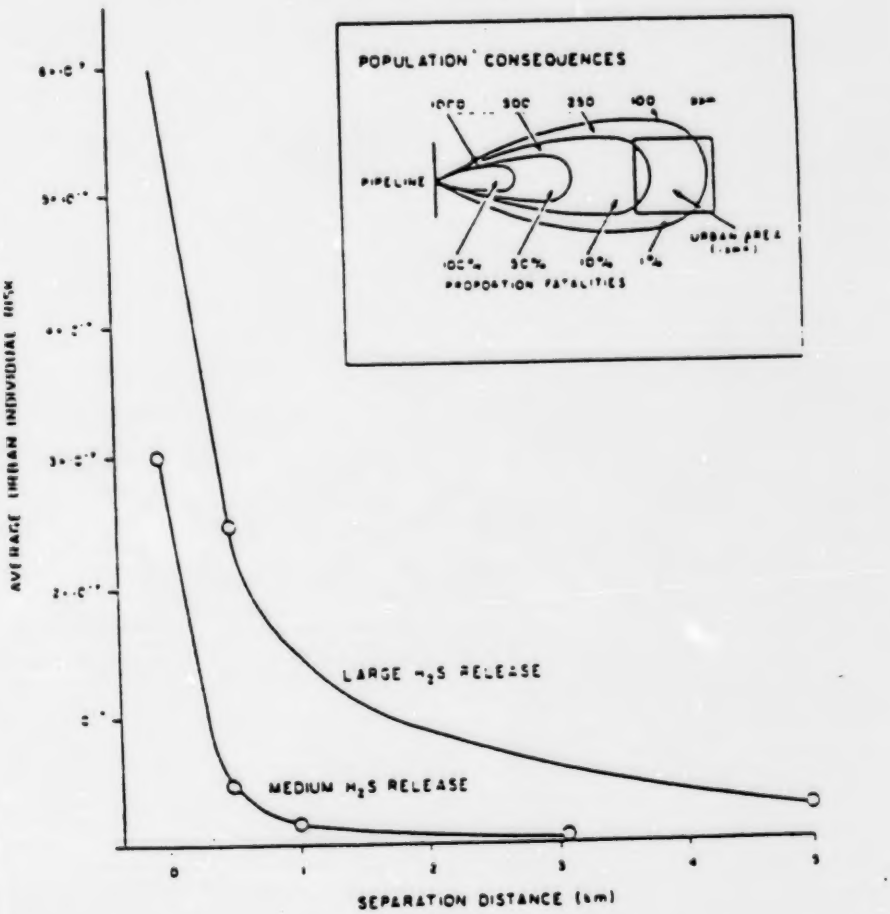

Fig. 1.1 Average urban individual risk versus separation distance for sour gas facilities

Concurrently, Alberta Environment again retained Dr. J.D. Whittaker to consolidate his risk work and produce a refined model for estimating individual risk. Alberta Environment also engaged another university consultant to develop an analytical blowdown solution and an "effective plume" model to handle the transient nature of the release. The release and dispersion model (Wilson 1979) also considered the relationship between concentrations indoors and outdoors and the fluctuations of concentration within the gas cloud. Uncertainty about the concentration-time effects for H_2S toxicity prompted Alberta Environment to commission an experimental investigation of lethality to white mice (Clanachan 1979). Lower concentra-

tions required longer exposure time to produce death, but at higher concentrations the time dependence disappeared beyond about 10 minutes.

Alberta Environment incorporated these results into a computer program (Choukalos 1980) for estimating individual risks as a function of distance from the pipeline (Fig. 1.2). An instantaneous exposure to 500 ppm was considered to be lethal. Input variables include pipeline characteristics (diameter, length, friction factor), gas characteristics (molecular weight, specific heat, temperature, pressure, composition), rupture location, atmospheric temperature, wind direction, atmospheric stability, daylight hours, building air exchange times, breathing rate, whether a person is indoors or outdoors, ground surface roughness, plume fluctuation intensity, turbulence intermittency and pipeline failure rate. The appropriate joint probability distributions are combined in accordance with the rules of probability calculus and the final probability determined by summing over all possible cases. Hence, in this approach risk is the probability that an individual will inhale a volume of air containing a concentration in excess of 500 ppm hydrogen sulphide.

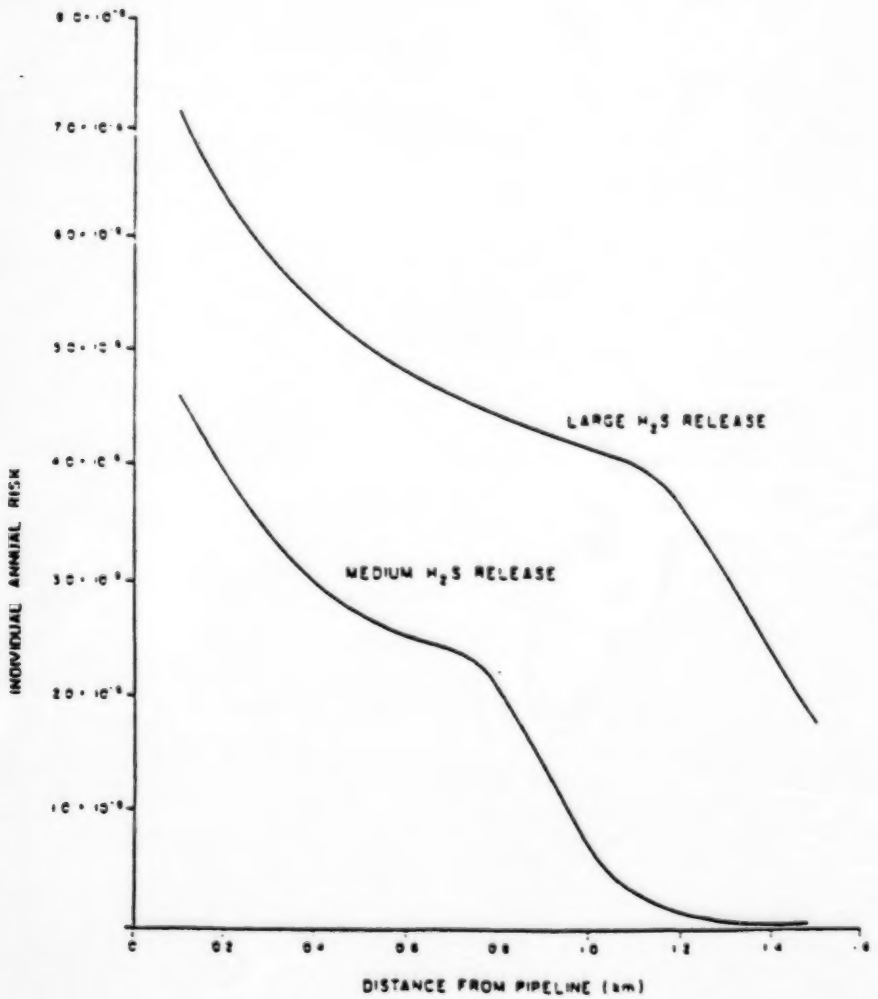

Fig. 1.2. Risk-distance curves for sour gas pipelines

In order to derive a distance for a buffer zone from the resulting graph, a level of acceptable risk must be established. Arguing that traditional risk comparisons were really "apples and oranges" Whittaker (1980) proposed that changes in life expectancy could be used as a consistent unit of measure, the benefits being represented by the rate of increase of life expectancy and the cost by the loss of life expectancy when a specified level of risk is imposed. The time taken to recover the loss then represents the "cost to benefit ratio". A risk of 10^{-5} leads to a recovery period of about four months while a risk of 10^{-4} requires about three years.

With preliminary results from these studies in hand, a new set of guidelines was proposed. The difficulties experienced in the administration of rules involving highly technical calculations were not to be repeated. Using the risk results and a "round numbers" approach, fixed distances were set for different sizes of sour gas facilities and different densities of subdivision (Table 1.1). The ERCB issued a new Interim Directive and a few months later the Alberta Planning Board amended the Subdivison Regulations.

Table 1.1 Summary of minimum distance requirements separating new sour[1] gas facilities from residential and other developments in the Province of Alberta

Level of sour gas facility	Potential H_2S Releases: Sour gas well release rate m^3/s	Potential H_2S Releases: Other sour gas facility release volume m^3	Minimum distance to various developments
1	<0.3	<300	No minimum distance except that associated with easement for right of way (usually about 15 m)
2	0.3 - 2.0	300 - 2000	0.1 km to individual permanent dwellings up to 8 per 1/4 section density. 0.5 km to urban centre or public facility.
3	2.0 - 6.0	2000 - 6000	0.1 km to individual permanent dwellings up to 8 per 1/4 section density. 0.5 km to an unrestricted country development. 1.5 km to an urban centre or public facility.
4	>6.0	>6000	case by case basis but not less than Level 3.

[1] sour gas is natural gas containing more than one mole percent hydrogen sulphide (H_2S).

Developers, landowners, gas producers, planners and regulators were generally satisfied with the new policy and the level of effort wound down quickly. Documentation of the risk methodologies did not appear for some time as staff were reassigned. Phases III and IV of the APIGEC isopleth prediction study received no further consideration, However, a general awareness of the sour gas hazard remains and continues to infiltrate the decision-making process at various levels in both government and industry.

1.2 ANALYSIS AND EVALUATION

Sour oil and gas had been produced in Alberta for several decades before the 1973 incident, hydrogen sulphide long being recognized as an occupational hazard. Alberta Workers' Health, Safety and Compensation had a number of safety regulations for the workplace and both government and industry were involved in education and

training programs. Between 1969 and 1973 there were 221 cases of H_2S exposure, with a 6% mortality rate. Between 1950 and 1976 there were 16 well blowouts covering an operating history of 45,700 well years. Between 1961 and 1976 there were 13 pipeline ruptures (major breaks) covering an operating history of about 95,000 sour gas pipeline years. Prior to the incident in central Alberta, most of the sour gas releases had been in relatively remote areas because the sour fields were located mainly in the foothills. As the population grew and petroleum exploration continued, it was inevitable that some day the two would collide. To the general public, that day was October 2, 1973, when there was extraordinary news media coverage of the large-scale evacuation accompanying the oil well blowout. Although the authorities had already encountered the land use conflict in northeast Calgary, this event served to thrust the problem into full public view and to give impetus to the efforts aimed at its solution.

In developing the response to the problem, information was amassed in three main categories:

1. **Failure frequencies stratified by cause and size of gas release.**

This information was incomplete and difficult to retrieve from the files because, of course, filing systems are developed around administrative functions, not specific data needs. Eventually a fairly complete record of pipeline breaks and well blowouts was assembled (Atwell et al. 1979).

2. **Concentration predictions involving:**

   (a) source conditions - size of leak, rise of gas, initial dilution, gas flow rate;
   (b) peak-to-mean fluctuations;
   (c) diffusion of a transient;
   (d) indoor-outdoor relations.

Meteorologists have been making diffusion predictions for several decades. The theory is well developed but the empirical input data are subject to considerable uncertainty. Also there was apparently a fundamental conflict between the "puff" models and the numerical models. The assumptions about the source were identified as the cause of many discrepancies in the various calculations. Both the model differences and the source conditions were investigated in research projects commisioned by APIGEC (1978; 1979).

3. **Health effects - lethal concentration limits, peak or time integrated (dose related).**

Knowledge of the lethality of hydrogen sulphide was based on a few animal experiments; accounts of accidental human deaths contained only estimated concentrations. The toxicity at high concentrations is not well documented for humans and probably never will be. This was not a major obstacle because one can always choose a concentration below any suspected toxic level. In order to clarify the dependence of lethality on concentration and time, a laboratory experiment with white mice was performed by Dr. A.S. Clanachan (1979).

The first step in solving the problem involved a review of the records on release frequencies and the toxicity of hydrogen sulphide. It was concluded that an exposure to a concentration of less than 100 ppm would not kill anyone. Since the time between a pipeline rupture and the arrival of a toxic gas cloud at any nearby location is measured in minutes, conventional disaster responses of warning and evacuation are not feasible. The only way to avoid a potential catastrophe is to exclude all settlement from the area where concentrations in excess of 100 ppm might be experienced. Later this was relaxed to exclude all settlement from the area potentially affected by "immediately dangerous-to-life" concentrations in excess of 500 ppm and to permit low density subdivision in the area between the 100 ppm and 500 ppm isopleth. In actual fact no member of the general public has ever been killed by an uncontrolled release of hydrogen sulphide. Occupational fatalities

were well documented; for instance, in November 1977, a tractor operator constructing a road to a well site tore open a sour gas line operated by another oil company and was killed when he misjudged his escape route and ran directly into the gas cloud.

Hence, the initial response was to add a large margin of safety; i.e. to choose a concentration isopleth well below known limits of fatality, its location being calculated using the maximum possible release and the worst possible source configuration and meteorological conditions. This approach was well received until all of its ramifications became apparent: some communities could not expand, large tracts of land could not be developed, land values fell, investors lost money, some citizens felt their rights as landowners were being abrogated, and gas producers were subject to long delays, protracted procedures and even denial of certain pipeline routes or well locations.

There was never any serious question about the benefits of sour gas, since it is part of the industry responsible for Alberta's prosperity. This is reflected in the original perception of the problem as "the encroachment of urban areas upon sour gas facilities" rather than as a pure land use conflict. Whittaker (1980) explored the benefits in a general way because risk anaysis is useful only in a comparison or tradeoff situation. While welfare economics provides the basis, risk benefit analysis flounders because of the difficulty of assigning monetary values to life. The "life expectancy" approach adopted by Whittaker allows one to assess the benefits and risks of technological progress in consistent units. Whittaker concluded that a sensible tradeoff occurs for risks in the order of 10^{-5} per person per year. The alternative is simply to compare the risk with that of a similar technology. It is difficult, however, to establish just what is "similar" in terms of benefits. Commercial air travel with a risk of order 10^{-5} per person per year is sometimes used to illustrate an existing tradeoff between risk and benefit. It is interesting that Whittaker's "life expectancy" approach yields a comparable target. In dealing with "average population risk" the shape of the risk-distance curve obviated the need to choose an acceptable level since there was a reasonable well-defined "point of diminishing returns".

In retrospect, the problem could have been solved much sooner, had the concept of risk analysis as a tool for public decision-making been accepted earlier and resources applied in that direction. "Worst case" assessment has the appeal of certainty and apparent simplicity. But in this situation there were far too many unacceptable ramifications. The complexity of isopleth calculations led first to a careful investigation of individual components to see whether they could be brought closer to reality. The APIGEC pipe burst tests were the culmination of this line of attack. When preliminary results removed the major uncertainties in the isopleth prediction methods and did nothing to change the unacceptability of the results, there was no other alternative but risk analysis. An intensive effort was mounted and the results were quickly transformed into new guidelines. Unfortunately Phase III and IV of the pipe burst experiments did not receive further consideration. The results of these comprehensive tests would have been equally as useful in the dispersion calculation component of risk analysis as in worst case assessment. When attention shifted toward risk analysis, interest in anything related to the earlier line of attack seemed to die instantly.

Concurrent to the development of assessment techniques and regulatory guides, industry and the ERCB were working to reduce the risk by technological means. Block valves were installed at closer spacings in sour gas pipelines and were equipped with flare depressurization systems. Internal surveys and x-rays for pipe condition were increased to detect corrosion-induced leaks. Pipelines were to be inspected by company personnel on foot to check for small leaks. The location of pipelines was conspicuously marked at roads, road allowances, fences and other points of external activity. Contractors excavating or working across pipeline right-of-ways were required to notify the pipeline operator prior to work commencement. Operation of the pipelines at lower pressure was also considered. About one-third of reported pipeline ruptures are due to outside forces rather than pipe corrosion or pipe defects. Technological measures cannot eliminate ruptures from this cause nor is it likely that significant reductions in frequency can be achieved. Blowout prevention

measures at gas wells were also improved. Remote and automatic controls were sometimes required to close a producing well. Sometimes H_2S detectors were also required. Servicing operations and equipment at wells was under surveillance 24 hours per day even when crews were not working on the rig. Blowout preventers (valves) on drilling rigs were upgraded and more thorough operator training initiated. Better planning also resulted from the growing awareness of the sour gas hazard. For example, the ERCB required sour gas operators to file detailed contingency plans showing what steps would be followed if an accident occurred. Applications for wells and pipelines, previously submitted separately, were now requested jointly. The ERCB is now asking for strategies on the development of entire gas fields.

Generally, everyone seemed satisfied with the final form of the regulations. There were still areas with considerable pressure for residential development in close proximity to sour gas facilities, but the emergence of a reasonable policy has made these easier to handle. However, as time passes and memory of the original large exclusion distances fades, the policy may be increasingly challenged by developers. On the other hand, if a pipeline near a sizable community should rupture and someone should actually be killed, public concern for greater safety could exert pressure in the opposite direction.

This case study illustrates several points with respect to risk management:

1. The response is evolutionary with successive steps depen-dent upon the acceptability of proposed measures;
2. Several government jurisdictions may be involved and success in dealing with a problem depends upon their cooperation and coordination;
3. The active involvement of the parties being regulated facilitates progress;
4. Considerable expenditures of money, both public and private, may be necessary to obtain information needed at various stages;
5. Acceptance of new concepts can be slow and incomplete;
6. An easily understood and administered form of regulation is preferred even in highly complex technical matters.

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